

COLLISION RECOVERY IN RFID SYSTEM

FAUZIA KHURSHEED & N. R. KIDWAI

Department of Electronics Communication Engineering, Integral University, Lucknow, Uttar Pradesh, India

ABSTRACT

RFID has made a revolutionary mark in identifying and tracking numerous of different objects. RFID has reduced the manual tracking to much higher extent. The key problem which is associated with the reading of RFID tags is the collision between tag response which makes the reading more difficult & time consuming. Collisions also reduce accuracy of the reader in reading tags. The purpose of this paper is to show how to recover from such collision on physical layer when there are more than two tags in a single slot. We are focusing on the protocol FSA and passive high frequency domain at 860-950MHz which follows EPC global standard for passive UHF RFID. Here the tags were modified slightly by adding a so called 'post-preamble' that facilitates channel estimation more specifically. It has been analyzed that the throughput of FSA systems with up to four receiving antenna that can recover up to eight tags on the collision in physical layer and can also acknowledge all tags involved in that collision in a single slot. Due to the higher collision recovery capabilities, the frame size can be significantly reduced and thus throughput can be increased. MATLAB software is used for performance evaluation at Rayleigh fading channel in MMSE Receiver and ZF Receiver at different signal to noise ratio. Throughput increases from 2.2 to 12.17 when post-preamble is considered with simple receivers and throughput increases to 18.36 when post-preamble concept is used with inclusion of SIC method.

KEYWORDS: ALOHA, RFID (Radio Frequency Identification), MMSE (minimum mean square error), FSA (Frame slotted ALOHA), ZF (Zero forcing) Receiver, SIC (Successive Interference Cancellation)

I. INTRODUCTION

RFID technology plays the vital role in the identification of objects to which RFID tags are attached and a reader is used to scan all the tagged objects without any direct contact with objects. The main components of a typical RFID system are reader and tag [1]. The reader has a transmitter-receiver module and antenna. The tag consists of integrated circuit, memory, and antenna. The tag is attached to the object which is to be identified. It can store information such as identification number and other details about the object. Each tag has a unique identification number. The reader and tags communicate through the electromagnetic waves. With RFID tags, each individual tagged item can be given its own identification number with many additional details about the object. RFID tags appear to be replacing the traditional barcode system for identification in various applications. The major advantages of RFID technology over barcodes are that the RFID-tagged objects does not require any line-of-sight with the reader for their identification and multiple objects can be read simultaneously. RFID technology is firming its claws drastically in the present world. Since RFID has many advantages and finds its applications in various fields, it is necessary to explore this technology and harness its potential. Though RFID technology came into existence several years ago, this technology did not completely take over the traditional barcode system due to some issues such as operating cost, privacy issues, technical issues, etc. Technical issues include identifying all the tagged objects efficiently and reliably. Since RFID reader can scan multiple tags simultaneously,

there is a problem of collision. So it is important to design a good anti-collision multi-tag identification algorithm for collision avoidance and to improve the performance of the system. Though several anti-collision algorithms have been developed, the problem of collision still occurs in RFID system. On the other hand, since the reader has no prior knowledge about the actual number of tags to be scanned, the reader has to know when to stop scanning the tags. Due to the stochastic nature of the reading process, it is not possible to expect to identify all tags with complete certainty [2]. Vogt [3], [4] proposed a probabilistic stopping criterion, which can achieve a predetermined assurance level probabilistically. However, such a method has very high computational complexity and it is difficult to implement practically. Therefore, there is a explore in low-complexity alternative methods that can be easily implemented in the practical system.

RFID System

RFID is a wireless technology; the main components of RFID system are tags and a reader. The reader sends and receives the information to/from the RFID tags through radio waves as shown in figure1.

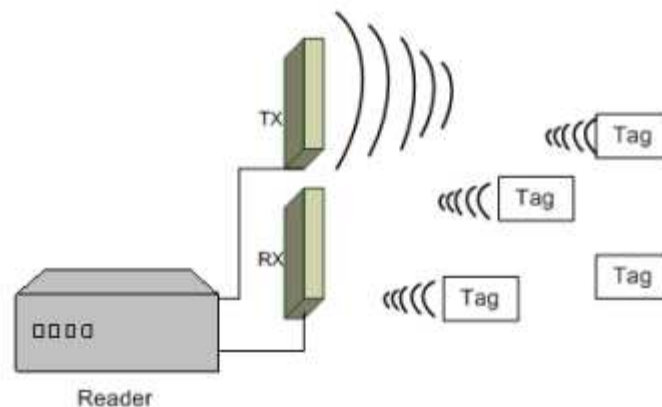


Figure 1: Passive UHF RFID Systems

The tags are the part attached to the objects to be traced or to be identified. These are interrogated by the reader to obtain their unique ID. There are four different RFID tags available they are- active, passive, semi-passive and beacon tag. Among active and passive RFID, passive RFID technology is most commonly used than active RFID technology due to certain issues like size, cost, life span, etc.

Classification of Tags in RFID System

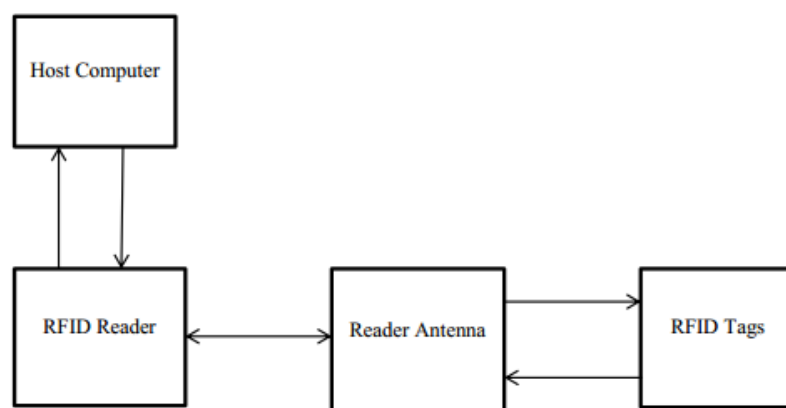


Figure 2: Block Diagram of RFID System

1. Active RFID Tags: Active RFID tags are equipped with internal power source such as battery to power up the integrated circuit and to send the signal to the reader. The operating range of active RFID tags is several hundred meters. They even have the capability to store any additional information received from the reader.

2. Passive RFID Tags: Passive RFID tags are not equipped with any power source. The radio frequency (RF) signal from the reader is needed to power them and also to communicate with the reader. As the tags have to receive the RF signal from the reader, there is a constraint on the operation range of passive RFID tags.

3. Semi-Passive RFID Tags: Semi-passive RFID tags have internal power source similar to active RFID tags. But this power source is used to power up the integrated circuit/microchip only. The tag uses the RF energy from the reader for the broadcasting of the signal.

4. Beacon RFID Tags: Beacon RFID tags send regular patterned radio signals with some limited information.

We are considering passive RFID tags because it is low in cost and also small in size and thus better for commercial use. Passive RFID extracts the power from the interrogation signal send by the reader. Accessibility of power is only within the range of the reader signal the strength requirement is high in order to trigger/power up the tag signal and the strength from the tag is low as it has to broadcast signal to the reader only after the reader has powered it.

Tag Management

Readers manage tag populations using the three basic operations shown in Fig.3 each of these operations comprises of one or more commands.

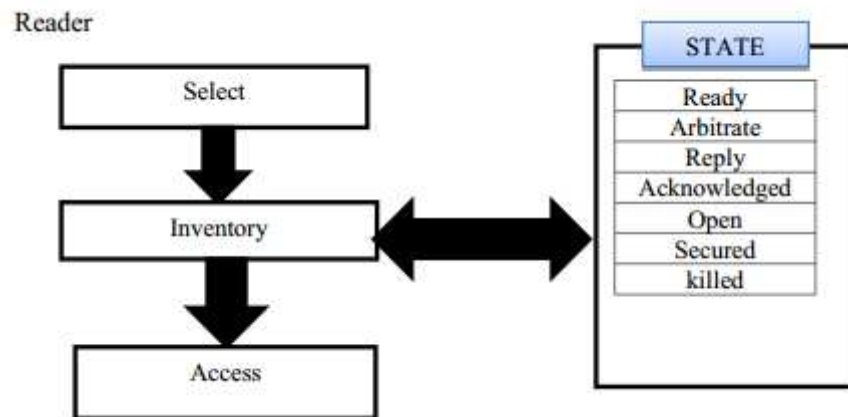


Figure 3: Reader/Tag Operations and Tag State

Select: It is the process by which a Reader selects a tag population for inventory and access. Interrogators may use one or more Select commands to select a particular Tag population prior to inventory.

Inventory: The process by which a Reader identifies Tags. A Reader begins an inventory round by transmitting a Query command in one of four sessions. One or more Tags may reply. The Reader detects a single Tag reply and requests the Protocol-Control (PC), Electronic Product Code (EPC), and Cyclic Redundancy Check 16 bits (CRC-16) from the Tag. An inventory round operates in one and only one session at a time. Fig.4 shows an example of a reader inventorying and accessing a single tag (CRC-16 not shown in transitions). RN16 is 16-bit random or pseudo-random numbers.

Access: The process by which a Reader transacts with (reads from or writes to) individual Tags. An individual Tag must be uniquely identified prior to access. Access comprises of multiple commands, some of which employ one-time-pad based cover-coding of the Reader to Tag link.

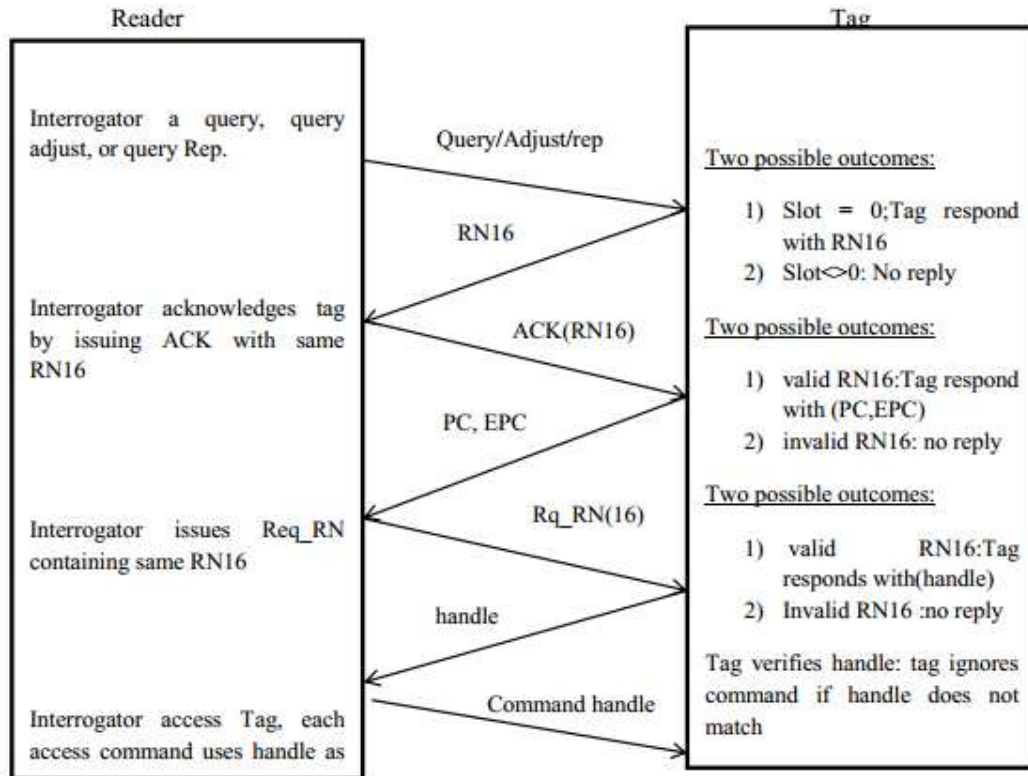


Figure 4: Example of Tag Inventory and Access

II. FSA ALGORITHM

Throughput of slotted ALOHA system is twice the throughput of pure ALOHA system, but its performance degrades when the number of tags in the system are large. Hence the concept of framed slotted ALOHA (FSA) was introduced. FSA system consists of frames and read cycles in addition to the slots. A frame is a group of time slots and a read cycle is the process of identifying tags which involves in a frame. The major difference between slotted ALOHA and FSA is that each tag can access only one time slot in one frame i.e., each tag can transmit its data at most once in a frame [1]. Consider that there are a large numbers of tags to be read; since the prefixes are common, only the remaining numbers of bits are read. To reduce collision, ALOHA is employed. As discussed previously, ALOHA is divided into slots, and each tag replies at particular slots. However, frame-slotted Aloha can also be categorized on the basis of different features. For example, basic frame slotted ALOHA protocol uses a fixedlength frame, which remains the same size until all tags have been read(for particular process) and the other is the dynamic framed-slotted ALOHA in this the frame size is altered according to the number of collision in the process.

The FSA is a time based anti-collision protocol in which the tag replies at different time intervals (slots). According to this algorithm, the reader usually keeps track of the earlier frames used to read the tags, and the slots that are utilized to read the tag.

	T1	Frame1				T2	Frame2			
		Slot 1	Slot 2	Slot 3	Slot 4		Slot 1	Slot 2	Slot 3	Slot 4
		Coll	Read	Empty	coll		Read	Coll	Read	Empty
Tag 1			1					1		
Tag 2					2		2			
Tag 3		3						3		
Tag 4					4				4	
Tag 5		5						5		

Figure 4: Framed Slotted ALOHA (FSA) in RFID System

In the framed slotted ALOHA, the reader sends a request to the tags within its range; the broadcast request contains frame length, which informs the tag of the slots and the time divisions. Tags then reply according to their time slots. For a particular time slot, the only states that could occur are whether the tag has been identified or two or more tag signals are collided, or the slot was left empty. This request can be considered as one cycle, before another request is broadcast within the range of the reader. After this cycle, the reader will analyze the empty slots and the slots where collision has occurred. After analyzing the slots, if there are slots on which a collision occurred, the reader then estimates, with the help of previous readings, the number of tags to be read. Then the reader sends a frame size request, which is calculated after estimating the number of tags. The reader also sets a threshold value for the collisions. Again, if the number of collisions is large, the number of tags can be estimated based on that number. On the other hand, if the number of collisions is small or the number of empty slots is large, then that would suggest that the number of total slot is very small.

Tag Collision Recovery Using FSA

Most of the RFID standards, as the EPC global standard for UHF RFID [2], introduce FSA to schedule the transmission of a tag population of N tags. Table 1 provides description of the important parameters and terms used in this paper. In the FSA system, the reader broadcasts the frame which comprises of 'F' slots issuing a QUERY command. The tags on receiving the frame randomly select a slot and transmit its unique ID to the reader in that selected slot. This arbitration process continues until the reader gets satisfied by the ID received from the tag end. The ID transmitted by the tag on the interrogation of the reader is a 16-bit number assigned in a format given by EPC global and is also termed as EPC (Electronic Product Code). The syntax for the EPC is shown in figure (5).

header	Organization number	Object class	Unique serial number
0-7	8-35	36-59	60-95

Figure 5: EPC Syntax

In an EPC the first 8 bits are header defining the version of protocol, organization number is of 28 bits assigned by the EPC global consortium used for identifying the organization controlling the data of the tag, next 24 bits are the object class which defines the type of object the tag is attached to, last 36 bits are unique serial number which is the identity for a particular tag.

Table 1: Symbols and Parameters Used

Variable	Description
N	number of tags within the read range
F	Number of slots in a frame
R	number of tags transmitting in the same slot
M	number of tags the reader is capable to resolve
J	number of tags the reader is capable to acknowledge
$i \in [1 \dots R]$	tag index
N_{RA}	number of receive antennas at the RFID reader
$E\{\mathcal{X}\}$	expected value of the random variable \mathcal{X}
h^*	conjugate complex of h
\mathbf{H}	bold terms indicate vectors or matrices
\mathbf{H}^H	Hermitian transpose of the matrix \mathbf{H}
J_C	Maximum number of tags with color C the reader acknowledges
$R_C \in [0 \dots N/C]$	Number of tags per slot with color C
$j \in [1 \dots R]$	Tag index per slot for $R > 0$
$i \in [1 \dots N_{RA}]$	Receive antenna index
$\mathbf{a}(t)$	Modulation vector $\in \mathbb{R}^{N \times 1}$
s_l	Collision scenario $l = 1, 2, \dots, S(R)$
T_{PSM}	Throughput per slot without post-preamble when $J=M$
T_{psC}	Throughput per slot with post-preamble when $J=M$

In the transmission of the frame multiple cases arises. They are-

- (a) If none of the tag responds in a slot such slot is termed as empty slot or an idle slot.
- (b) If only one tag responds in a slot it is called single slot.
- (c) And if more than one tag responds in a slot collision occurs and the slot is termed as collided slot.

The expected number of slots with 'R' tags for a random variable is given by [1] -

$$E\{X_R\} = F \binom{N}{R} \quad (1)$$

Where, $E\{\}$ denotes the expected value.

The readers of the conventional RFID system can only read data in the single slot resulting into the maximum average throughput = 0.368 successful readouts per slot. This can be achieved only if the frame size (F) is made equal to the total number of tags within the read range (N) i.e. ($F=N$).

In case of ($R \leq M$) colliding tags, it can possibly be recovered as the reader selects only one tag out of these S tags and acknowledge it, while the other tags are ignored. In each slot with ($R \leq M$) only a single tag is identified. Hence, the average throughput is stated as-

$$T = \frac{1}{F} \sum_{R=1}^M E\{X_R\} \quad (2)$$

And it can be further evaluated from equation (1) as –

The maximum average throughput for ideal frame size is given as-

$$\sum_{R=1}^M \binom{N}{R} \left(\frac{1}{F_{ideal}}\right)^{R+1} \left(-\frac{1}{F_{ideal}}\right)^{N-R-1} \left(-\frac{1}{F_{ideal}}\right)^0 \quad (3)$$

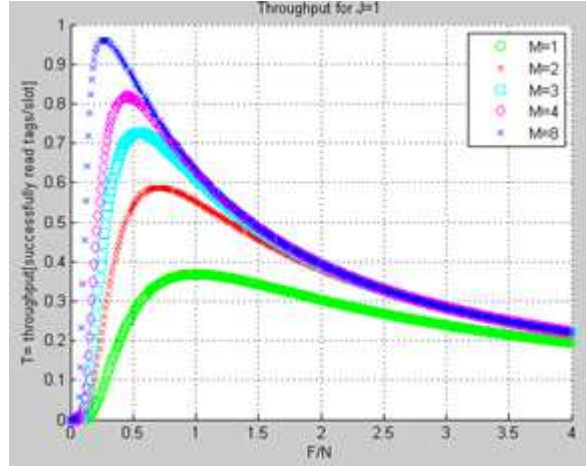


Figure 6: Throughput for M=1,...,4,8 and J=1

Figure 6 shows the expected throughput of the receivers that are capable to recover from collisions up to M tags, for $N = \dots$. this throughput is estimated by varying the value of M i.e. M=1, 2..., 8 while the number of acknowledged tags (J) are assumed to be unity (J=1). For M=2 and up to 4 the throughput has been already achieved by C. Angerer. It can be stated that tags adjust in a shorter frame size for maximal throughput. Motivated by such receivers we are onto develop the signal model for collisions in section IV and SIC reader receivers in section V before that the concept for post preamble is proposed in section III

III. CHANNEL ESTIMATION USING POST-PREAMBLE

In the EPC global standard for UHF RFID [1] a tag response to the Query command consists of a preamble followed by a 16 bit-random number or pseudo-random number. Since the preamble is identical for all tags involved in a collision, we cannot use it for the channel estimation. Therefore an extension of the tag signal is done by including a “post-preamble” as shown in Fig.7 In order to fulfill the channel estimation requirements, “post-preamble” is designed to be different for each tag, and is mutually orthogonal. Tags encode the backscattered data as either FM0 baseband or Miller modulated of a subcarrier at the data rate [1]. The challenge was to offer optimal channel estimation at minimum “post-preamble” length.

The length of the “post-preamble” is strongly influenced by the number of the tags to be separated in the system. The maximum number of tags that we are trying to separate in this work is eight ($R_{\max} = 8$) and thus we are using a set of eight mutually orthogonal sequences.



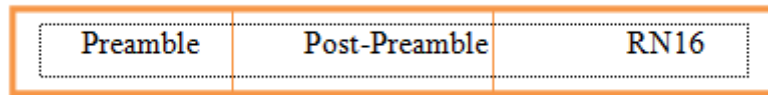


Figure 7: Extension Provided to the Tag Signal by Using “Post-Preamble”.

Search-algorithm: Due to the extremely high number of possible vector sets, it is necessary to optimize the search algorithm for mutually orthogonal sequences. The algorithm iterates over increasing set sizes and in each iteration it searches for all unique sets of mutually orthogonal sequences of the size of the particular iteration. A set S_i of sequences p_k with exactly i different sequences is called a set of mutually orthogonal sequences if it fulfills the following property:

- In order to fulfill the channel estimation requirements post-preamble is designed to be

1). Different for each Tag.

2). mutually orthogonal.

b). Length of the “post-preamble” is influenced by the number of the tags to be separated.

c). FM0 coding:

1) Doubles the amount of bits after the encoding process

2) Does not allow the use of well-known orthogonal sequences.

d). Search-algorithm:

The algorithm iterates over increasing set sizes and with each iteration it searches for all unique sets of mutually orthogonal sequences p of the size of that particular iteration.

$=1, k=1, 0$ (4)

Else, S_i is set of mutually orthogonal sequence.

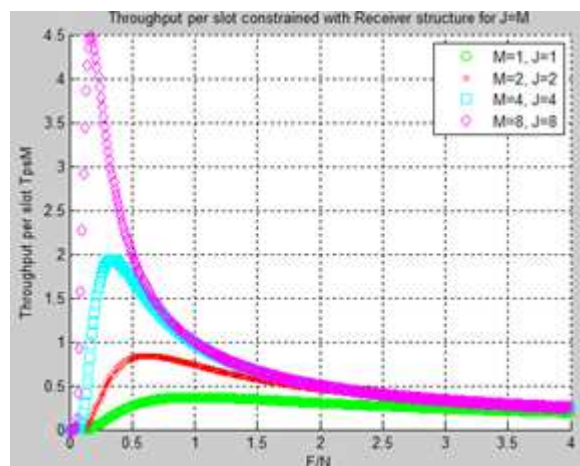


Figure 8: Throughput per Slot Constrained with Receiver Structure for (J=M) without Post-Preamble

The maximal theoretical throughput per slot, obtained for an optimal reader that can recover from a collision of $R \leq M = 2N_{RA}$ tags and can acknowledge ($J = M$) in the case of perfect channel knowledge [8], reads as follows:

$$= \sum_{R=1}^M (5)$$

The equation (5) states the throughput of the receiver without the inclusion of post-preamble for $J=M$ (i.e. number of acknowledged tags are equal to number of resolved tags). The estimated throughput is shown in figure 8.

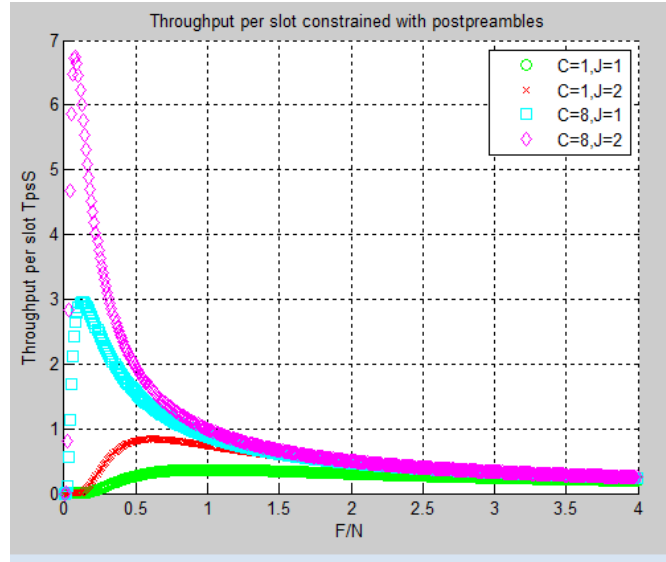


Figure 9: Throughput Per Slot Curves Constrained with Post-Preambles. throughput as a Function of Slots Per tag Population $F=N$ for $C = \{1; 8\}$ colors and $J = \{1; 2\}$ Acknowledgements Following Equation (6)

A post-preamble is added in order to support channel estimation, and the desired case is that all tags involved in a collision have orthogonal post-preambles to distinguish between them. If uniform distribution of post-preambles is assumed between tags in the population, we can view the tag population of size N as C partitioned tag populations, each with the average size $N=C$, where C is the number of different colors (number of different post-preambles in a set). Theoretically, as long as there is a tag of unique color among the active tags in a slot, we can differentiate the related signal and acknowledge this tag. Even if there are two tags with the same color involved in a collision, we expect to recover from that particular collision and to acknowledge both tags by applying the projection method proposed in [7]. Now, under the assumption that we can acknowledge up to J_C tags with identical color per slot, given the tag population size N , the frame size F and C different post-preambles in a set, the Tps is as follows:

$$= \sum_{Rc=1}^{Jc} \binom{N}{Rc} \left(\frac{1}{C} \right) \quad (6)$$

Where Rc denotes the number of tags per slot with identical color.

The throughput for condition $J=M$ using post-preamble concept is shown in figure 9.

Table 2: Maximal Throughput per Slot Constrained with Post-Preambles

System	Fopt	Tps	RTps	RTpf
C=1 J=1	1	0.368	1.000	1.000
C=1 J=2	0.618	0.841	2.285	3.697
C=8 J=1	0.125	2.955	8.030	47.096
C=8 J=2	0.077	6.757	18.361	174.824

The table above shows the optimal ratio $F_{opt}=N$, maximal theoretical throughput per slot constrained with post-preambles T_{ps}^c , its relative improvement and relative improvement in throughput per frame.

IV. SIGNAL MODEL AND CONSTELLATIONS IN TAG COLLISION

1) Signal Model of Tag Collisions on the Channel

The RFID system with passive tags forms the half-duplex communication system. Every communication system follows two steps-

- Downlink communication (Reader to tag)
- Uplink communication (Tag to reader)

a) **Downlink Communication**- The downlink communication in RFID system states the interrogation established by the reader to the tags as shown in figure (10).

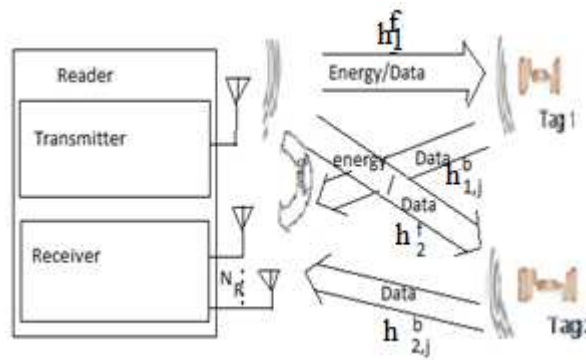


Figure 10: Communication between RFID Reader and Several Tags

In case of passive tags the communication is initiated by the reader i.e. the interrogation signal is sent to tags by the reader as a carrier signal given as-

$$S^{Reader}(t) = \sin(\omega_c t)$$

Where,

$\omega_c = 2\pi f_c$ and f_c is the carrier frequency.

The signal sent from the reader to tag provides energy to the passive tag and also results into the leakage at the receiver antenna 'j'. This leakage at receive antenna 'j' is stated as-

$$S_j^{Leak}(t) = |L_j| e^{j\phi_j} \sin(\omega_c t) \quad (7)$$

Where,

ϕ_j Denote the phase shift due to the propagation delay.

$|L_j|$ – Amplitude of the leakage at receiver antenna 'j' which is supposed to be constant for one transmission.

In the downlink phase the tag does not communicate and hence only absorbs the energy from the signal transmitted by the reader.

b) **Uplink Communication**- The uplink communication refers to the phase of communication from the tag end i.e. in this part the tag replies back to the reader using backscatter modulation.

R tags are transmitting in a slot, each tag 'I' belongs to [1...R] and changes from absorb state '0' to the reflect state '1'. Thus the backscatter signal is given by-

$$S_{tag,I}(t) = |h_I^f| \sqrt{|\Delta\sigma_I|} a_I(t) \sin(\omega_c(t) + \varphi) \quad (8)$$

Where,

- Reader to tag channel attenuation
- Phase shift for reader to tag
- Phase shift due to modulation of tag
- Normalized differential radar cross section area given as [8]

$$|\Delta\sigma_I| = |\rho_I^r - \rho_I^g|^2$$

Where,

- Complex reflection coefficient for absorb state '0' and the reflect state '1' respectively.
- Modulation signal. Given as-

$$a_I(t) = \sum_k a_I[k] p(t - kT_I - \tau_I)$$

Where,

- $a[k] \in [0,1]$ is the transmitted symbol.
- $p(t)$ - Pulse shape of modulation signal.
- Different symbol period.
- delay in start of modulation phase.

For simplicity of the model the noise in the uplink (forward link) is neglected and all noise considered at receiver is additive white Gaussian pass-band noise.

The R backscattered signal for collision slot are distorted by carrier leakage and noise

$$S_j^{pb}(t) = |h_{j,r}^f| |h_{j,r}^f| \sqrt{|\Delta\sigma_I|} a_I(t) \sin(\omega_c t + \varphi_I^f + \varphi_I^{ls} + \varphi_{j,r}^f) + S_j^{leak}(t) + n_j^{pb}(t) \quad (9)$$

In this model it is assumed that the channel attenuation and phase shift and also the tag modulation parameters, does not change considerably during the transmission of a particular packet.

2) Signal Constellation in Baseband of the Receiver

On receiving the collided signal on the receiver, the reader firstly down-converts it to the baseband. The down-converted baseband signal at j^{th} receive antenna is given as-

$$= \sum_{l=1}^L h_{lj}^b \sqrt{\Delta\sigma_l} a_l(t) \quad (10)$$

Where,

h_{lj}^f is complex-valued forward channel-coefficient, h_{lj}^b is complex-valued backward channel-coefficient.

$\Delta\sigma_l$ is complex-valued normalized differential radar cross-section,

L_j is the complex-valued carrier and $n_j(t)$ is the complex-valued white Gaussian noise at each antenna j with noise power spectral density N_0 . The receive signals of each antenna, into a vector form can be rewritten as-

$$\mathbf{S}(t) = \mathbf{s}\mathbf{A}(t) + \mathbf{i} + \mathbf{n}(t) \quad (11)$$

In the above equation $\mathbf{S}(t)$, \mathbf{i} are the column vectors of $\mathbf{S}(t)$ with the elements $s_i(t)$ respectively. The term $\mathbf{A}(t)$ denotes the $N_R \times R$ tag to reader channel matrix with elements $a_{ji}(t)$ in row j and column i , $\mathbf{A}(t)$ and \mathbf{s} are $R \times R$ modulation and radar cross-section matrices with $a_i(t)$ and σ_i as their elements and 0 elsewhere, respectively and \mathbf{i} is the $R \times 1$ vector with the forward coefficient h_{lj}^f . Equation (11) can be equivalently formulated to:

$$\mathbf{S}(t) = \mathbf{H}\mathbf{a}(t) + \mathbf{i} + \mathbf{n}(t) \quad (12)$$

V. COLLISION RECOVERY RECEIVERS

With the consideration of above model, we are here undertaking the multiple antenna receivers in account. This class of receiver separates the signals from the collided slot into the components corresponding to the single tags.

Organizing the signals and decoding them is the next step to be performed individually for each resolved tag signal which is followed by sampling, under this all the resolved tag signals may be sampled with their respective symbol frequency and further will be received successfully by the RFID reader. We are basically focusing here on dual antenna receivers, which are also capable of recovering from slots with eight tags at most.

1) Zero-Forcing (ZF) Receiver: In order to separate the signal components exploiting multiple receive antennas, we first propose the well-known zero-forcing receiver [7]:

$$\hat{\mathbf{a}} = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H \mathbf{S} \quad (13)$$

In the above equation \mathbf{H}^H refers to the Hermitian Transpose (i.e. conjugate transpose) of the matrix \mathbf{H} . Unlike of the single antenna receivers ZF receiver exploits the different spatial signatures in order to separate the signals, resulting into no projection loss.

2) Minimum-Mean-Square-Error (MMSE) Receiver

It is well known in literature [7], that the zero-forcing (ZF) receiver suffers from noise enhancement due to the inversion of matrix $\mathbf{H}^H \mathbf{H}$. Whereas, MMSE receiver takes into account both the interference and the noise, and also balances the error:

$$\hat{\mathbf{a}} = \mathbf{G}(\mathbf{S} - \mathbf{i}) + \mathbf{i} \quad (14)$$

Where,

$$\mathbf{G} = (\mathbf{I} + 4\mathbf{N}_0)^{-1}. \quad (15)$$

And

$$\mathbf{C} = (\mathbf{I} - \mathbf{G})\mathbf{E}\{\mathbf{a}\} \quad (16)$$

In equations (14,15,16) \mathbf{I} refers to the $(N_R \times N_R)$ identity matrix.

3) Successive Interference Cancellation (SIC) Receiver

Furthermore, in this work SIC receivers are proposed which performs by decoding the streams sequentially. For example let's assume a case, when $R = 4$ tags are colliding and two collided tags have the same color(scenario 1) while the others have different unique colors (scenario 2), the vector form of the signals received by $N_{RA} = 2$ antennas [6] is as follows:

$$\mathbf{r} = \begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix} \mathbf{a}_1 + \begin{bmatrix} h_{1,2} \\ h_{2,2} \end{bmatrix} \mathbf{a}_2 + \begin{bmatrix} h_{1,3} \\ h_{2,3} \end{bmatrix} \mathbf{a}_3 + \begin{bmatrix} h_{1,4} \\ h_{2,4} \end{bmatrix} \mathbf{a}_4 \quad (13)$$

Where, \mathbf{r} (t) and \mathbf{a}_i are part of the received signals containing the post-preamble from antennas 1 and 2, respectively.

In scenario where, tags 3 and 4 shares same post-preamble, p_c , and cannot use an LS channel estimation technique [5] then to overcome this situation, a successive interference cancellation (SIC) method is used.

Figure 11 and 12 shows the comparative study of ZF, ZF-SIC receivers and MMSE, MMSE-SIC receivers at Rayleigh fading channel respectively.

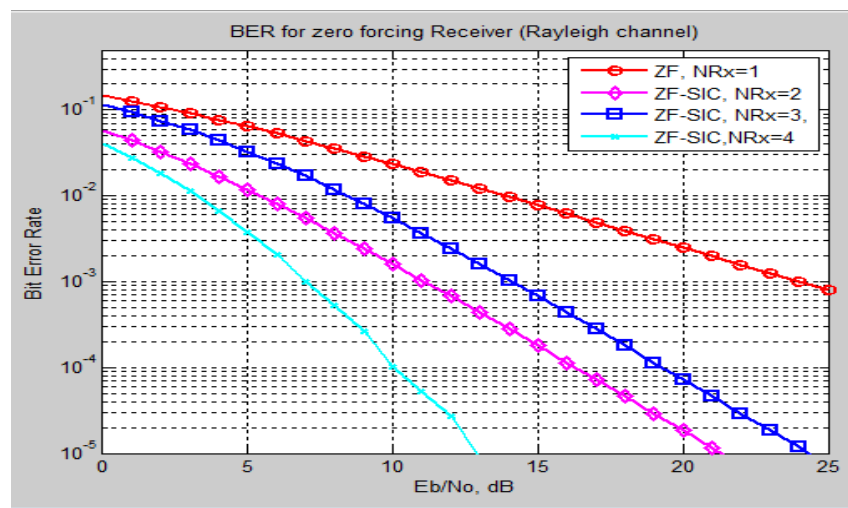


Figure 11: BER for ZF and ZF-SIC Receiver

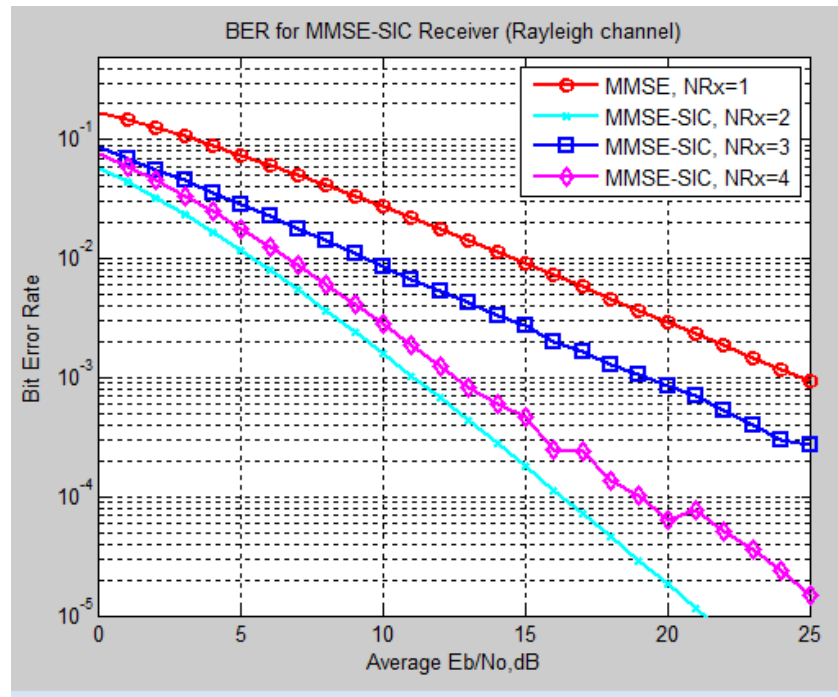


Figure 12: BER for MMSE and MMSE- SIC Receiver

IV. RESULTS

We have analyzed the theoretical throughput of an FSA RFID system. It studied the influence of several parameters on the system throughput Figure 6, 8, 9 and found the maxima of the theoretically throughput for receivers with different collision recovery factors and for different receivers architectures. It has investigated the benefit of an additional post-preamble to the throughput and observed that without taking into account the receiver structure and successive interference cancellation method. It is possible to increase the system throughput by more than 1 8.36 times. On the other hand if the receiver structure is taken into account, then a throughput increase of more than 12.17 times can still be achieved for a reader capable of successfully reading and acknowledging up to eight tags per slot. When the tags are augmented by post-preambles, so based on this several collision scenario can be differentiate and if the probability of scenarios that can be resolved and the number of tags is successfully decoded. For the two types of receivers MMSE receiver & Zero forcing Receiver is very much capable to resolve the collision with minimum bit error rate but the performance of MMSE receiver is better than ZF receiver.

V. DISCUSSIONS AND CONCLUSIONS

The concept Presented in this paper shows that the number of collisions between the RFID tags, and their data can be extracted is dependent on the number of Receiving Antenna that is $NR \geq M$. Firstly , a mathematical model of the two tags signal using standard signal representation techniques is discussed. Using this model and the utilizing the knowledge of the tag signal it is possible to distinguish & decode individual tag by the MMSE Receiver and zero-forcing Receiver. For the decoding , firstly the concept of SIC(successive interference cancellation) is used to estimate individual tags signals, which is then removed from the residual, enabling further decoding of weaker tag signals .

REFERENCES

1. [1] C Angerer, R Langwieser, M Rupp, "RFID reader receivers for physical layer collision recovery," *IEEE Trans. Comm.* Vol.58, No.12, pp.3526–3537, Dec 2010
2. C Angerer, G Maier, MV Bueno-Delgado, M Rupp, J Vales-Alonso, "Single antenna physical layer collision recovery receivers for RFID readers". in Proceedings of the *IEEE International Conference on Industrial Technology (ICIT'10)*, Vina del Mar-Valparaiso, Chile, 14–17 Mar 2010
3. B Knerr, M Holzer, C Angerer, M Rupp, "Slot-wise maximum likelihood estimation of the tag population size in FSA protocols". *IEEE Trans. Comm.* Vol. 58, No.2, pp.578–585, Feb 2010
4. J Kimionis, A Bletsas, AG Dimitriou, GN Karystinos, "Inventory time reduction in Gen2 with single- antenna separation of FM0 RFID signals". in Proceedings of *IEEE International Conference on RFID-Technologies and Applications (RFID-TA)*, Sitges, Spain, 15–16 Sept 2011.
5. D.-Y. Kim, H.-S. Jo, H. Yoon, C. Mun, B.-J. Jang, and J.-G. Yook,
6. J Kaitovic, R Langwieser, M Rupp, Advanced collision recovery receiver for RFID. in Proceedings of the 4th International EURASIP Workshop on RFID Technology, Torino, Italy, 27
7. Jelena Kaitovic, Robert Langwieser and Markus Rupp, "A Collision Recovery Receiver for RFID" *Institute of Telecommunications*, Vienna University of Technology, May 22 nd ; 2012.
8. P. V. Nikitin, K. V. S. Rao, and R. D. Martinez, "Differential RCS of RFID tag," *Electron. Lett.*, vol. 43, no. 8, Apr. 2007

